IEC 61290-10-5

Edition 1.0 2014-05

INTERNATIONAL STANDARD

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colour inside

Optical amplifiers – Test methods – Part 10-5: Multichannel parameters – Distributed Raman amplifier gain and noise figure

Amplificateurs optiques – Méthodes d'essai – Partie 10-5: Paramètres à canaux multiples – Gain et facteur de bruit des amplificateurs Raman répartis

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CONTENTS

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OPTICAL AMPLIFIERS –
TEST METHODS –

Part 10-5: Multichannel parameters –
Distributed Raman amplifier gain and noise figure

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The text of this standard is based on the following documents:

CDV	Report on voting
86C/1142/CDV	86C/1233/RVC

Full information on the voting for the approval of this standard can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all parts in the IEC 61290 series, published under the general title *Optical amplifiers – Test methods*, can be found on the IEC website.

The committee has decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC web site under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

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OPTICAL AMPLIFIERS – TEST METHODS –

Part 10-5: Multichannel parameters – Distributed Raman amplifier gain and noise figure

1 Scope and object

This part of IEC 61290 applies to distributed Raman amplifiers (DRAs). DRAs are based on the process whereby Raman pump power is introduced into the transmission fibre, leading to signal amplification within the transmission fibre through stimulated Raman scattering. A detailed overview of the technology and applications of DRAs can be found in IEC TR 61292-6.

A fundamental difference between these amplifiers and discrete amplifiers, such as EDFAs, is that the latter can be described using a black box approach with well-defined input and output ports. On the other hand, a DRA is basically a pump module, with the actual amplification process taking place along the transmission fibre. This difference means that standard methods described in other parts of IEC 61290 for measuring amplifier parameters, such as gain and noise figure, cannot be applied without modification.

The object of this standard is to establish uniform requirements for accurate and reliable measurements, using an optical spectrum analyser (OSA), of the following DRA parameters:

a) channel on-off gain;
b) pump unit insertion loss;
c) channel net gain;
d) channel signal-spontaneous noise figure.

The measurement method is largely based on the interpolated source subtraction (ISS) method using an optical spectrum analyser, as described and elaborated in IEC 61290-10-4, with relevant modifications relating to a DRA.

All numerical values followed by (‡) are suggested values for which the measurement is assured. Other values may be acceptable but should be verified.

NOTE General aspects of noise figure test methods are reported in IEC 61290-3.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60825-1, *Safety of laser products – Part 1: Equipment classification and requirements*

IEC 61291-1, *Optical amplifiers – Part 1: Generic specification*

IEC 61291-4, *Optical amplifiers – Part 4: Multichannel applications – Performance specification template*

IEC TR 61292-4, *Optical amplifiers – Part 4: Maximum permissible optical power for the damage-free and safe use of optical amplifiers, including Raman amplifiers*

3 Terms, definitions and abbreviations

3.1 Terms and definitions

3.1.1
Raman pump power
optical power produced by the DRA to enable Raman amplification of signal channels

Note 1 to entry: The Raman pump power shall be at a lower wavelength than the signal channels.

3.1.2
fibre span
length of fibre into which signal channels and Raman pump power are introduced, and Raman amplification of the signal channels takes place via stimulated Raman scattering

3.1.3
co-propagating configuration
forward pumping configuration
configuration whereby the Raman pump power is coupled to the input of the fibre span such that the signal channels and Raman pump power propagate in the same (forward) direction

3.1.4
counter-propagating configuration
backward pumping configuration
configuration whereby the Raman pump power is coupled to the output of the fibre span such that the signal channels and Raman pump power propagate in opposite directions

3.1.5
pump module
module that produces Raman pump power and couples it into the connected fibre span

Note 1 to entry: If the pump module is connected to the input of the fibre span, then both the incoming signal channels and Raman pump power are coupled to the fibre span.

Note 2 to entry: If the pump module is connected to the output of the fibre span, then the pump power is coupled into the fibre span, while the signal channels exiting the fibre span pass through the pump module from the input port to the output port.

Note 3 to entry: In this standard, the convention will be used whereby the input port of the pump module is defined as the port into which the signal channels enter, while the output port is defined as the port through which the signal channels exit. Thus, in co-propagating configuration the Raman pump power exits the pump module from the output port, while in counter-propagating configuration the Raman pump power exits the pump module from the input port.

3.1.6
channel on-off gain
$G_{\text{on-off}}$
ratio of the channel power at the output of the fibre span when the pump module is operational to the channel power at the same point when the pump module is not operational

3.1.7
pump module channel insertion loss
IL
ratio of the channel power at the input of the pump module to the channel power at the output of the pump module

3.1.8
channel net gain
G_{net}
channel on-off gain minus the pump module channel insertion loss, in dB

3.1.9
channel equivalent noise figure
$NF_{\text{sig-ASE,eq}}$
channel noise figure due to signal-spontaneous beat noise (see IEC 61290-3) of an equivalent discrete amplifier placed at the output of the fibre span which has the same channel gain as the DRA channel on-off gain, and generates the same amount of ASE as that generated by the DRA at the output of the fibre span.

3.2 Abbreviated terms

ASE	amplified spontaneous emission
DRA	distributed Raman amplifier
EDFA	Erbium doped fibre amplifier
FWHM	full-width half-maximum
GFF	gain flattening filter
ISS	interpolated source subtraction
NF	noise figure
RBW	resolution bandwidth
OSA	optical spectrum analyser
OSNR	optical signal-to-noise ratio
PCF	power correction factor
SMF	single-mode fibre
SSE	source spontaneous emission
VOA	variable optical attenuator

4 DRA gain and noise figure parameters – Overview

NOTE Unless specifically stated otherwise, all equation and definitions in this clause and onwards are given in linear units, and not dB.

Figure 1 shows the application of DRAs in co-propagating (forward pumping) and counter-propagating (backward pumping) configurations. As a general rule, counter propagating configuration is much more widely used compared to co-propagating configuration.

As with any amplifier, one of the main parameters of interest is the channel gain (see IEC 61291-1 and IEC 61291-4). However, unlike discrete amplifiers, where the channel gain is simply defined as the ratio of the channel power at the output port to the channel power at the input port, with a DRA, the situation is more complex. In principle, the DRA includes both the pump module, which supplies the pump power, and the fibre span, where the actual amplification takes place. Thus, one option for defining channel gain is to define it as the ratio of the channel power at point C (Figure 1) to the channel power at point A, while the pumps are operational. However, since this definition also include the fibre span loss, which is often larger than the gain supplied by the Raman pumps, this definition is not very useful.

A much more useful quantity is the channel on-off gain, which is defined as the ratio of the channel power at the output of the fibre span when the Raman pumps are on to the channel power at the same point but when the pumps are off (see the graphs in Figure 1).

$$G_{\text{on-off}} = \frac{P_{\text{on}}}{P_{\text{off}}} \tag{1}$$

In practice, the channel on-off gain may be measured at any point following the fibre span, for example point C for co-propagating configuration, or points B and C for the counter-propagating configuration.

Another parameter of interest for DRAs is the pump module channel insertion loss, which is defined as the ratio of the channel power at the input port of the pump module to the channel power at the output port of the pump module (points A and B for co-propagating configuration, and points B and C for counter propagating configuration).

$$IL = \frac{P_{\text{pump unit input}}}{P_{\text{pump unit output}}} \tag{2}$$

Since no amplification takes place within the pump module, this is just passive insertion loss, and is not affected by the status of the pumps (on or off).

The channel on-off gain and pump module channel insertion loss can be combined into a single quantity, the channel net gain, which is defined in dB as

$$G_{\text{net}}(\text{dB}) = G_{\text{on-off}}(\text{dB}) - IL(\text{dB}) \tag{3}$$

The channel net gain is particularly useful for counter-propagating configuration, as it may be directly measured in linear units as the ratio of the channel power at point C when the pumps are on to the channel power at point B when the pumps are off. When the pump module includes a gain flattening filter (GFF) to tailor the spectral shape of the Raman gain, then the channel net gain includes the effect of the GFF, as opposed to the channel on-off gain which does not (i.e. the channel on-off gain has a non-flat dependence on the channel wavelength). For the co-propagating configuration, the channel net gain has less physical meaning, and it is more common to separately define the channel on-off gain and pump module channel insertion loss.

Another important parameter relevant to a DRA is the channel equivalent noise figure (NF) due to signal-spontaneous beat noise. This quantity is only relevant to counter-propagating configuration. The channel equivalent NF of a DRA is defined as the NF of an equivalent discrete amplifier placed at the output of the fibre span, which provides the same amount of channel gain as the DRA channel on-off gain, and generates the same amount of amplified spontaneous emission (ASE) as that generated at the fibre span output by the DRA. The channel equivalent noise figure (in dB) due to signal-spontaneous beat noise is given by (see IEC 61290-3):

$$NF_{\text{sig-ASE,eq}} = 10\log_{10}\left(\rho_{\text{ASE,B}} / \left(G_{\text{on-off}}\, h\nu\right)\right) \tag{4}$$

where

$\rho_{\text{ASE,B}}$ is the ASE spectral density at the channel wavelength λ (in both polarization modes) measured at the output of the fibre span (point B in the counter-propagating configuration of Figure 1);

$\nu = c/\lambda$ is the channel frequency;

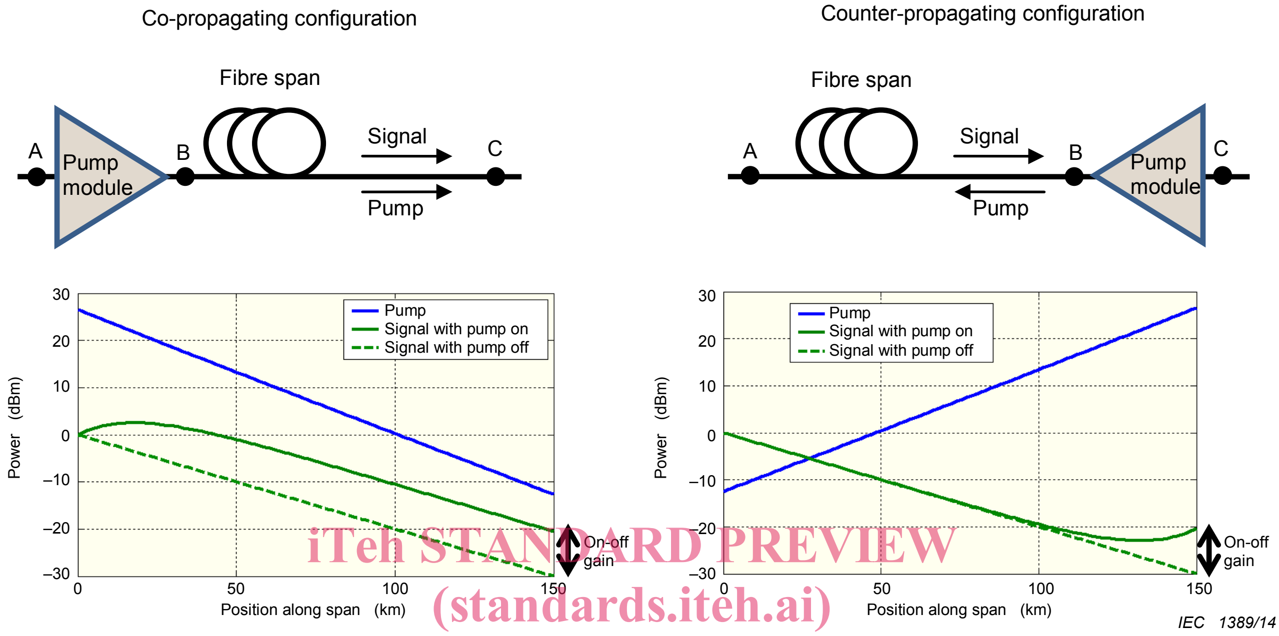
h is Planck's constant.

Using the relation between the channel on-off gain and the channel net gain, it is easily shown that the channel equivalent NF is also given by

$$NF_{\text{sig-ASE,eq}} = 10\log_{10}\left(\rho_{\text{ASE,C}} / (G_{\text{net}} h\nu)\right) \quad (5)$$

where

$\rho_{\text{ASE,C}}$ is now measured at point C.



NOTE The graphs show the evolution of pump and signal along the fibre span.

Figure 1 – Distributed Raman amplification in co-propagating (left) and count-propagating (right) configurations

When measuring DRA gain and NF, the following issues should be considered:

a) The purpose of the measurement: whether the purpose is to measure the DRA performance in relation to a specific span of fibre in the field, or characterize DRA performance with respect to a generic fibre type in the laboratory. This is elaborated in Annex A.

b) Whether or not the input signal configuration can affect the measurement due to pump depletion and/or signal-signal Raman scattering. This is elaborated in Annex B.

5 Apparatus

5.1 General

Figures 2 through 4 show the measurement set-up for measurement of DRA parameters in counter-propagating and co-propagating configurations. The various components comprising the set-up (as well as other components used for calibration) are described in the following subclauses.

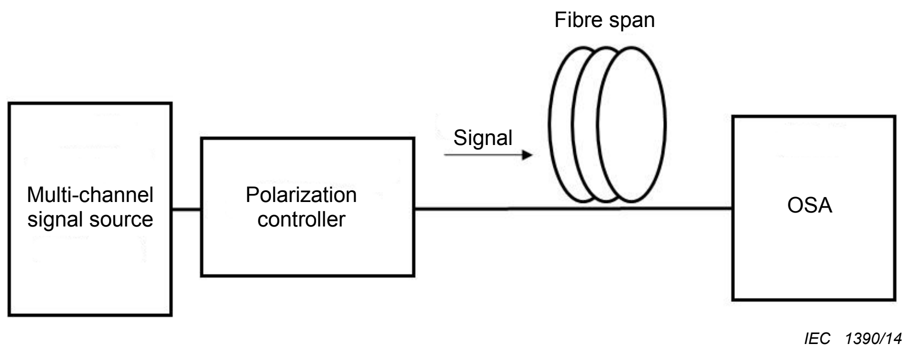


Figure 2 – Measurement set-up without a pump module

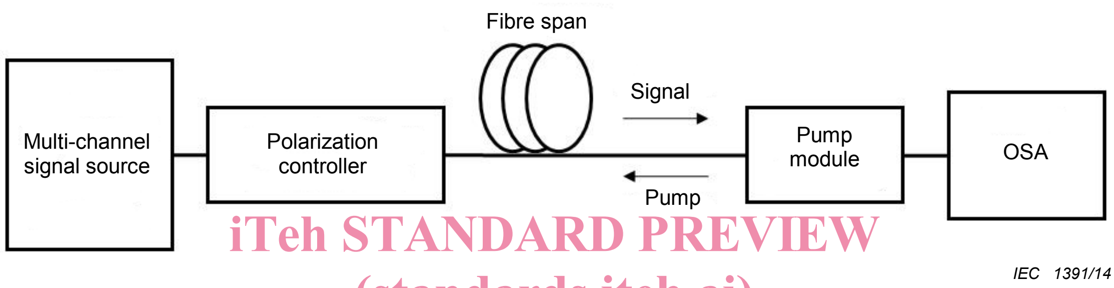


Figure 3 – Measurement set-up for counter-propagating configuration

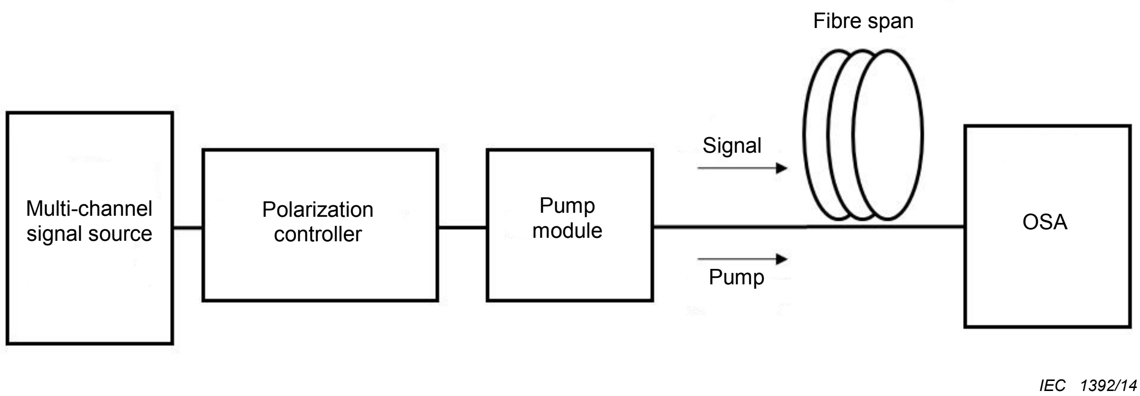


Figure 4 – Measurement set-up for co-propagating configuration

5.2 Multi-channel signal source

Figure 5 shows a possible implementation of a multi-channel signal source. This optical source should consist of n laser sources where n is the number of channels for the test configuration. The full width at half maximum (FWHM) of the output spectrum of each laser source shall be narrower than 0,1 nm (‡)[1] so as not to cause any interference to adjacent channels. The suppression ratio of the side modes of the single-line laser shall be higher than 35 dB (‡). The output power fluctuation shall be less than 0,05 dB (‡), which is more easily attainable with an optical isolator placed at the output port of each source. The wavelength

1 Suggested value.

accuracy shall be better than ±0,1 nm (‡) with stability better than ±0,01 nm (‡). The spontaneous emission power within a 1 nm window surrounding the laser wavelength should be at least 40 dB below the laser output power.

The purpose of the channel combiner is to multiplex all the laser sources onto a single fibre. The channel combiner should have polarization dependent loss better than 0,5 dB (‡), and wavelength dependent loss better than 1 dB (‡).The reflectance from this device shall be smaller than –50 dB (‡) at each port.

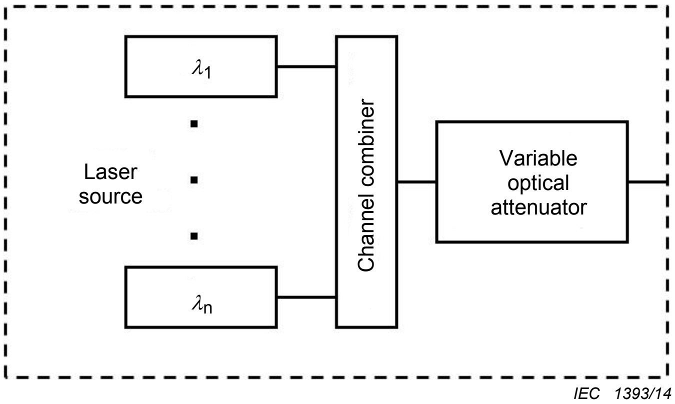


Figure 5 – Possible implementation of a multi-channel signal source

The multi-channel signal source should provide the ability to control the power of each individual laser, so as to achieve a desired power configuration of the channels. This can be achieved either through direct control of each laser source, or by placing a variable optical attenuator (VOA) after each laser source. The multi-channel signal source should preferably also provide the ability to control the power of all the sources simultaneously, e.g. using a variable optical attenuator (VOA) as shown in Figure 5. If one or more VOA is used, then its attenuation range and stability shall be over 40 dB (‡) and better than 0,1 dB (‡), respectively. The reflectance from this device shall be smaller than –50 dB (‡) at each port. If a VOA is placed after the channel combiner, the wavelength flatness over the full range of attenuation shall be less than 0,5 dB (‡).

5.3 Polarization controller

This device shall be able to convert any state of polarization of a signal to any other state of polarization. The polarization controller may consist of an all-fibre polarization controller or a quarter-wave plate rotatable by a minimum of 90°, followed by a half-wave plate rotatable by a minimum of 180°. The reflectance of this device shall be smaller than –50 dB (‡) at each port. The insertion loss variation of this device shall be less than 0,5 dB (‡). The use of a polarization controller is considered optional, but may be necessary to achieve the desired accuracy for cases when the DRA exhibits significant polarization dependent gain.

5.4 Optical spectrum analyser

The optical spectrum analyser (OSA) shall have polarization sensitivity less than 0,1 dB (‡), stability better than 0,1 dB (‡) and wavelength accuracy better than 0,05 nm (‡). The linearity should be better than 0,2 dB (‡) over the device dynamic range. The reflectance from this device shall be smaller than –50 dB (‡) at its input port. The OSA shall have sufficient dynamic range and support sufficiently small resolution bandwidth (RBW) to measure the noise between channels. For 100 GHz (0,8 nm) channel spacing, the dynamic range shall be greater than 55 dB at 50 GHz (0,4 nm) from the signal.